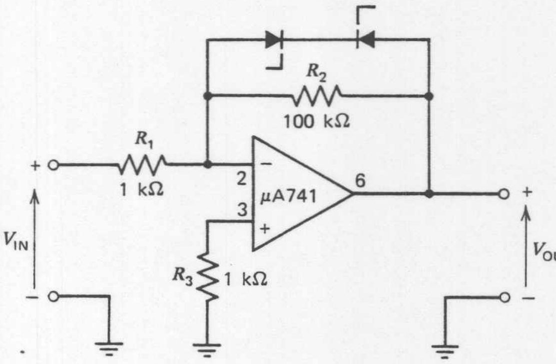

Figure 4-101. Clipping amplifier [*note:* $V_{OUT}/V_{IN} = -R_2/R_1$ if $|V_{OUT}| \leq V_Z + 0.7$ V where V_Z is the Zener-diode breakdown voltage].

When D_1 is reverse-biased in either circuit, a large differential voltage may appear between the inputs of the LM101A. This is necessary for proper operation and does no damage since the LM101A is designed to withstand large input voltages. These circuits will not work with amplifiers protected with back-to-back diodes across the inputs. Diode protection conducts when the differential-input voltage exceeds 0.6 V and would connect the input and output together. Also, unprotected devices such as the μA709, are damaged by large differential-input signals.

Occasionally, it is desirable to limit the output swing of an amplifier to within specific limits. This can be done by adding nonlinear elements to the feedback network as shown in Figure 4-101.

The Zener diodes quickly reduce the gain of the amplifier if the output tries to exceed the limits set by the Zener voltages. When the Zeners are not conducting, the gain is determined by the feedback resistors R_1 and R_2.

Precision Rectifiers[4]

The basic precision rectifier circuit is shown in Figure 4-102. In this circuit the diodes act as perfect rectifiers because each diode's forward voltage drop is effectively divided by the op amps open-loop gain at the input-signal frequency of interest. The circuit, however, does have some drawbacks. One of the most serious is that the op amp's input-offset voltage is amplified by the dc open-loop gain of the amplifier (50,000 minimum for an op amp such as the μA741). This causes an error output voltage because one of the diodes is always ON and the other OFF. The error occurs when the input signal multiplied by the open-loop gain at the frequency of interest is less than the input-offset voltage multiplied by the dc gain.

A second serious problem is that, with a very low-input signal, the amplifier's input-noise voltage is amplified by the open-loop gain. If the level of input noise is high enough, the diodes turn ON, causing a dc error to be present at $+V_{OUT}$ and $-V_{OUT}$.

The op amp used in the circuit of Figure 4-102 should have a high gain-bandwidth product. Devices like the LM101A and 108A, with feedforward compensation, and the NE531 are ideally suited for this application.

[4] E. R. Hnatek, "Use Integrated Circuits in Transformerless dc-to-dc Converters," *EDN*, Feb. 5, 1973.

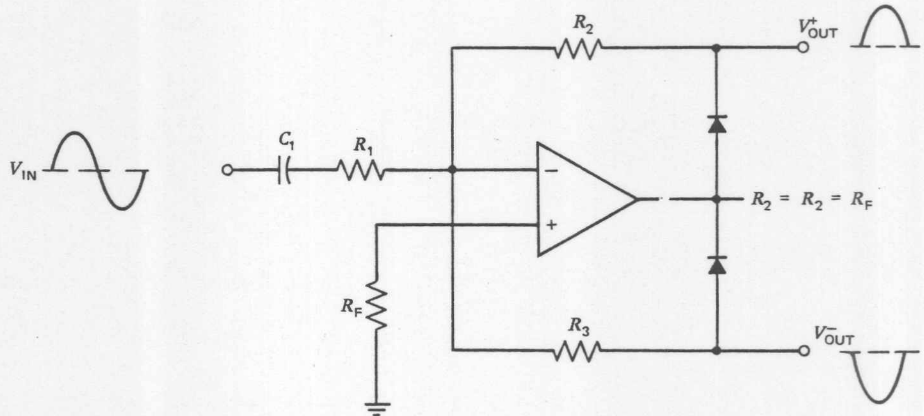

Figure 4-102. The basic precision rectifier circuit suffers from errors in its dc output. (Courtesy *EDN*.)

Figure 4-102 can be modified to overcome the above disadvantages, as shown in Figure 4-103. The addition of C_2, R_4, and R_5 brings the dc closed-loop gain of the circuit to unity. Thus, the op amp's input-offset voltage is only amplified by 1. The addition of C_3 reduces the gain-bandwidth product when the diodes are not conducting. This reduces the gain available to amplify the input noise voltage. However, C_3 should be chosen with care, since it also affects the circuit's gain-bandwidth product with the diodes conducting.

Another variation of the precision rectifier is shown in Figure 4-104. In this circuit, the addition of R_6, C_4 and R_7, C_5 serves two purposes: These components reduce the peak-rectified voltage at $+V_{OUT}$ and $-V_{OUT}$ to an average dc voltage, and they cause the circuit to act as a voltage-doubler.

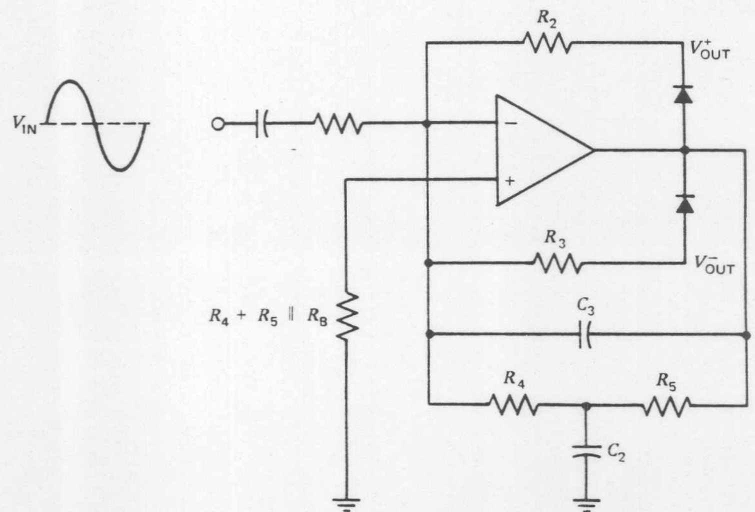

Figure 4-103. Improved performance in the basic precision rectifier is achieved with the addition of R_4, R_5, C_2, and C_3 [*note:* $R_2 = R_3 = R_B$, $R_4 = R_5$]. (Courtesy *EDN*.)

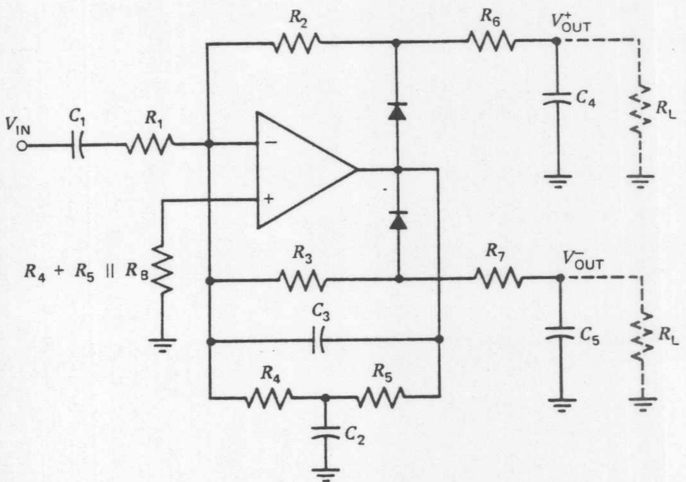

Figure 4-104. This version of the precision rectifier circuit also acts as a voltage-doubler [*note:* $R_2 = R_3 = R_B, R_4 = R_5 = R_C, R_6 = R_7 = R_A, C_3 = C_4, 10R_B = R_A, 20R_L \geq R_A$]. (Courtesy *EDN*.)

The time constant of R_6C_4 and R_7C_5 in Figure 4-104 should be set at 1/10 of the single sine-wave period of the highest frequency to be rectified. As a minimum, the values of R_B and R_L are at least ten times R_A; then, the discharge time of C_4 and C_5 is at least ten times as long as the charge time.

Another method of improving circuit performance is to use hot-carrier or Schottky diodes for the rectifiers. These diodes have much lower forward-voltage drops as a function of forward current, which increases the available circuit gain. Figure 4-105 depicts a circuit that provides accurate full-wave rectification.

The circuits in Figures 4-99 and 4-100 are relatively slow. Since there is 100% feedback for positive-input signals, it is necessary to use unity-gain frequency compensation. Also, when D_1 is reverse-biased, the feedback loop around the amplifier is opened and the input stage saturates. Both of these conditions cause errors to appear when the input frequency exceeds 1.5 kHz. A higher performance precision half-wave rectifier is shown in Figure 4-106. This circuit will provide rectification with 1% accuracy at frequencies from dc to 100 kHz. Further, it is easy to extend the operation to full-wave rectification for precision ac/dc converters.

This precision rectifier (Figure 4-106) functions somewhat differently from the circuit in Figure 4-99. The input signal is applied through R_1 to the summing node of an inverting op amp. When the signal is negative, D_1 is forward-biased and develops an output signal across R_2. As with any inverting amplifier, the gain is R_2/R_1. When the signal goes positive, D_1 is nonconducting and there is no output. However, a negative feedback path is provided by D_2. The path through D_2 reduces the negative-output swing to -0.7 V, and prevents the amplifier from saturating.

Since the LM101A is used as an inverting amplifier, feedforward compensation can be used. Feedforward compensation increases the slew rate to 10 V/μsec and reduces the gain error at high frequencies. This compensation allows the half-wave rectifier to operate at higher frequencies than the previous circuits with no loss in accuracy.

The addition of a second amplifier converts the half-wave rectifier to a full-wave

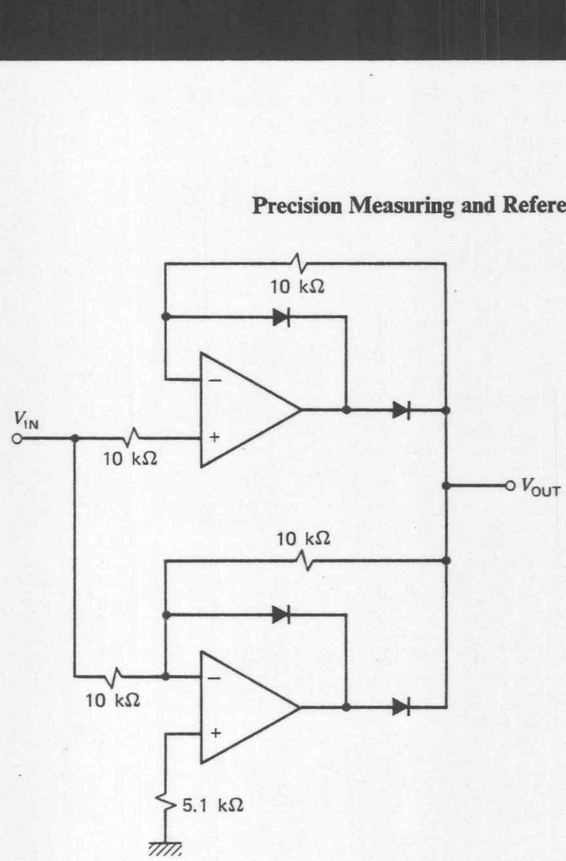

Figure 4-105. Precision full-wave rectifier. (Courtesy *EDN*.)

rectifier. As is shown in Figure 4-107, the half-wave rectifier is connected to inverting amplifier A_2; A_2 sums the half-wave-rectified signal and the input signal to provide a full-wave output. For negative-input signals the output of A_1 is zero and no current flows through R_3. Neglecting for the moment C_2, the output of A_2 is $-(R_7/R_6)V_{IN}$. For positive-input signals, A_2 sums the currents through R_3 and R_6; and

$$V_{OUT} = R_7 \frac{V_{IN}}{R_3} - \frac{V_{IN}}{R_6} \tag{4-15}$$

If R_3 is $(1/2)R_6$, the output is $(R_7/R_6)V_{IN}$. Hence, the output is always the absolute value of the input.

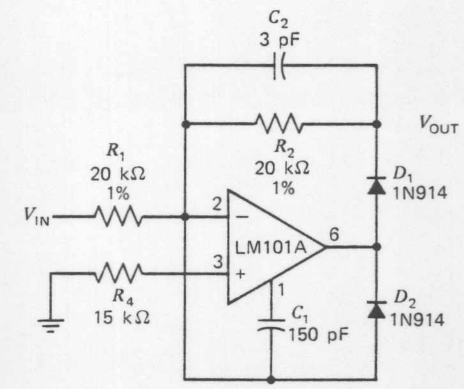

Figure 4-106. Fast half-wave rectifier. (Courtesy *EDN*.)

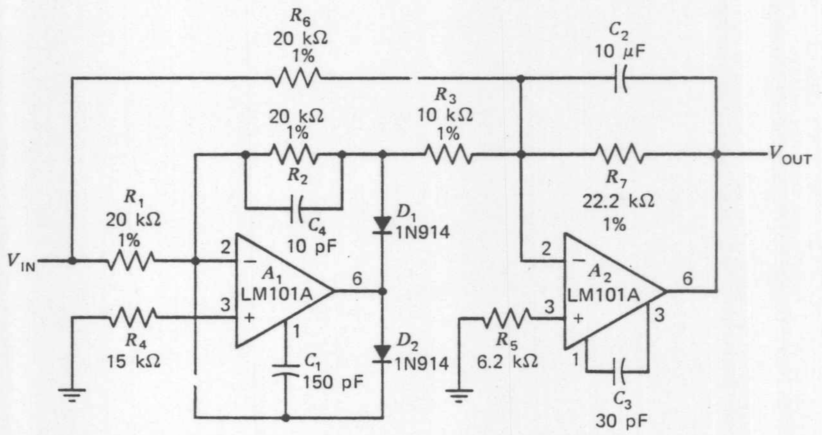

Figure 4-107. Precision ac/dc converter [*note:* feedforward compensation can be used to make a fast full-wave rectifier without a filter]. (Courtesy *EDN*.)

Filtering, or averaging, to obtain a pure dc output is very easy to do. A capacitor C_2 placed across R_7 rolls off the frequency response of A_2 to give an output equal to the average value of the input. The filter time constant is R_7C_2, and must be much greater than the maximum period of the input signal. For the values given in Figure 4-107, the time constant is about 2.0 sec. This converter has better than 1% conversion accuracy to above 100 kHz and less than 1% ripple at 20 Hz. The output is calibrated to read the rms value of a sine-wave input.

As with any high-frequency circuit some care must be taken during construction. Leads should be kept short to avoid stray capacitance and power supplies bypassed with 0.01-μF disk ceramic capacitors. Capacitive loading of the fast rectifier circuits must be less than 100 pF or decoupling becomes necessary. The diodes should be reasonably fast and film-type resistors used. Also, the amplifiers must have low-bias currents.

Wide–Range Voltage Controlled Amplifier

When a field-effect transistor is operated as a voltage-controlled resistor, it is usually limited to a relatively small dynamic signal-voltage range. This is due to the nonlinearity of its drain-source resistance over a wide range of drain-source voltage.

But a wide-range voltage-controlled amplifier can be realized if a pair of FETs is connected in the bridge configuration as shown in Figure 4-108. The inverting terminal of the operational amplifier is kept at virtual ground, permitting the range of each FET's drain-source voltage to remain small, regardless of how broad the actual signal-voltage range is. This also assures that the excursions of V_{DS} will remain well within the FET's pinch-off region.

The circuit's voltage-transfer function can be written as:

$$A_V = -(R_2/R_1) + N(R_1 + R_2)/R_1 + NR_2r_{on}[l - (V_{GS}/V_P)] \qquad (4\text{-}16)$$

where r_{on} is the on-resistance of the right-hand FET, V_{GS} is the gate-source voltage, and V_P is the pinch-off voltage. Variable N represents a resistance ratio:

$$N = r_{on}/(r_{on} + R_1) \qquad (4\text{-}17)$$